REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
13/03/2009	Final	01/04/2008-31/3/2009

4. TITLE AND SUBTITLE
A Neuroimaging Study of the Acquisition of Expertise in Action Recognition

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00173-08-1-G013

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER
201494

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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Washington, DC 20375

10. SPONSOR/MONITOR'S ACRONYM(S)
NRL

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release, Distribution is Unlimited

20100901112

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Recognition of the actions of others is critical in warfare environments and may be particularly important during unconventional warfare. It is unclear, however, how a soldier might become expert in action recognition. Here we examined the hypothesis that expertise in action recognition relies on neural systems involved in performing an action. Participants were trained to perform a difficult, bimanual motor action, or a nonmotor action recognition task, for 25 days. Using functional magnetic resonance imaging (fMRI), we examined changes in neural activity involved in the action recognition network as a function of learning to perform the novel action. Results indicated that learning to perform the motor action was associated with increased fMRI activity in primary motor and ventral premotor cortices, and that these increases were correlated with changes in performance. In contrast, learning the nonmotor action recognition task led to decreased activity in motion processing regions. These findings establish a quantitative link between action performance and neural activity in the action recognition system.

15. SUBJECT TERMS
action recognition, motor, learning, fMRI

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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DEFENSE SCIENCES OFFICE

James Thompson, PhD

A Neuroimaging Study of the Acquisition of Expertise in Action Recognition

03/13/09

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- Tracey Wheeler, PhD
  - **Research Assistant**
    - (04/01/08 - 08/31/09)
- Shira Levy
  - **Research Assistant**
- Wendy Baccus
  - **Research Assistant**

Hypothesis and Goals

- Recognition of the actions of others is critical in warfare environments:
  - Determining friend or foe
  - Assessing risk
  - Crowd control

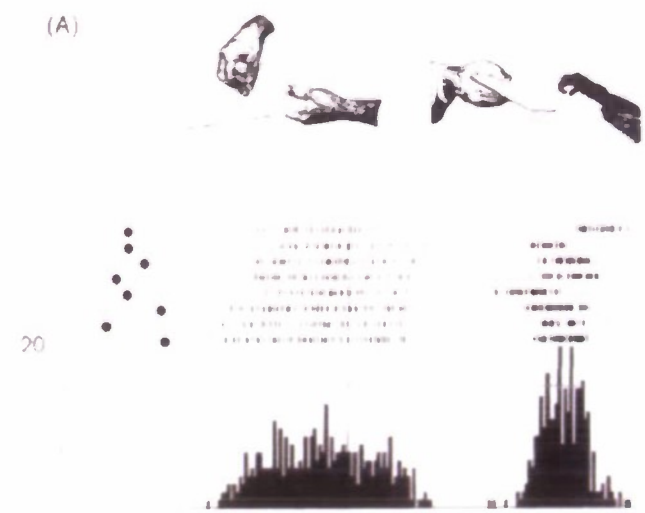
- Particularly important in unconventional warfare

- **How can soldiers become experts in action recognition?**

Hypothesis and Goals

- Action recognition relies on neural systems engaged both when one ***performs*** action and when one ***observes*** action.

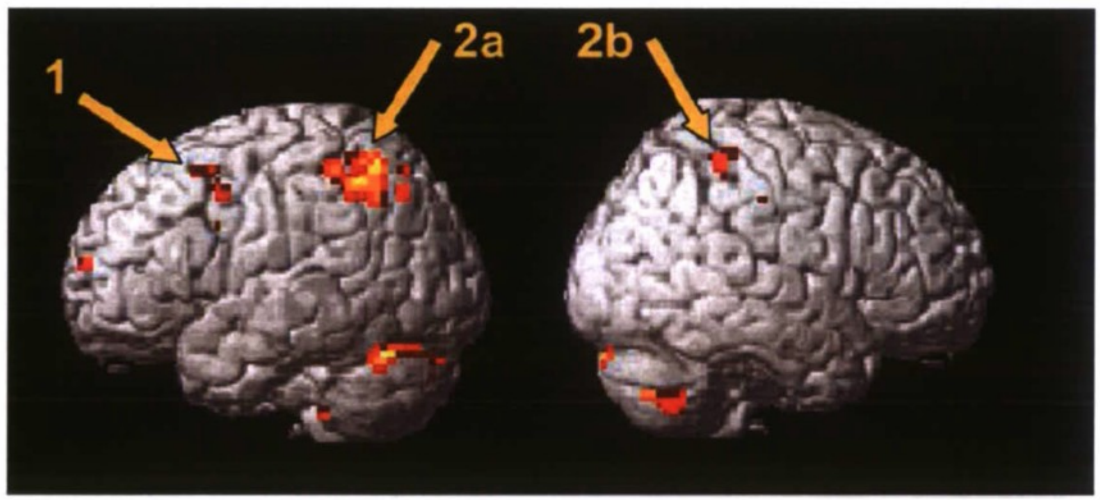
- Mirror Neuron System (MNS)
  - Neurons in monkey F5 (ventral premotor) fire when monkey performs grasp or sees grasp



Gallese et al., (1996) *Brain*

Hypothesis and Goals

- Experts in *performing* an action show greater neural activity in human MNS when *observing* someone performing that action.



Greater fMRI activity in human MNS associated with motor expertise. (1 = dorsal premotor, 2a,b = inferior parietal). Calvo-Merino et al (2006) *Current Biology*

Hypothesis and Goals

- **Hypothesis:** Expertise in action recognition relies on the ability to draw upon motor representations of action performance.
  - Learning to perform action confers an advantage when it comes to recognizing an action, relative to learning a task visually. This is mediated by the Mirror Neuron System (MNS)

- **To what extent does become an expert in action recognition rely on developing motor representations vs visual representations?**

Hypothesis and Goals

- **Goals:**
  - To determine the trajectory from naïve to expert in action recognition;
  - Establish a quantitative link between a) action performance ability and b) action recognition ability and neural activity in MNS

Experimental Overview

- **Goal 1:** To determine the trajectory from naïve to expert in action recognition with training of:
  - A novel action without visual input (blindfolded)
  - Compared to learning to recognize an action visually, without learning to perform it
- Train for 20min a day, 5 days a week, for 5 weeks (25 days total)

Experimental Overview

- **Goal 2:** Establish a quantitative link between a) action performance ability and b) action recognition ability & neural activity in MNS
  - Examine the extent to which increases in action performance predict changes in action recognition

Experimental Overview

- Training Group 1 (n = 11) **Nonvisual Motor Learning**
  - Continuous one-ball juggling task
    - Participant must continuously catch-and-throw a juggling ball
    - Drops, pauses of more than 1s counted as end of sequence
    - Performance = mean number of continuous catches in 20min session

Experimental Overview

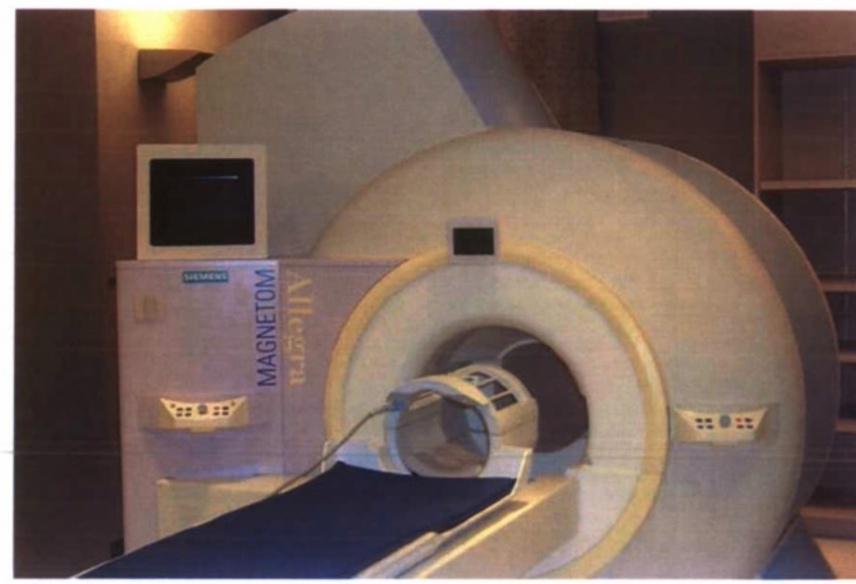
- Training Group 2 (n = 11) **Visual Nonmotor Learning**
  - Counting the number of catches in videos of motor task
    - Participant given criteria for drops, pauses, continuous catches
    - Performance = (Number of counted catches / Number of actual catches) *100

Experimental Overview

- Outcomes: **Action Recognition Ability**
  - Does motor or visual training improve the ability to use subtle kinematic/dynamic cues associated with actions?
  - Point-light videos of continuous juggling task
    - Movies pauses just before catch or drop
  - Participant must predict of they think it will be a catch or drop
    - Accuracy (% correct)
    - Reaction Time (ms)

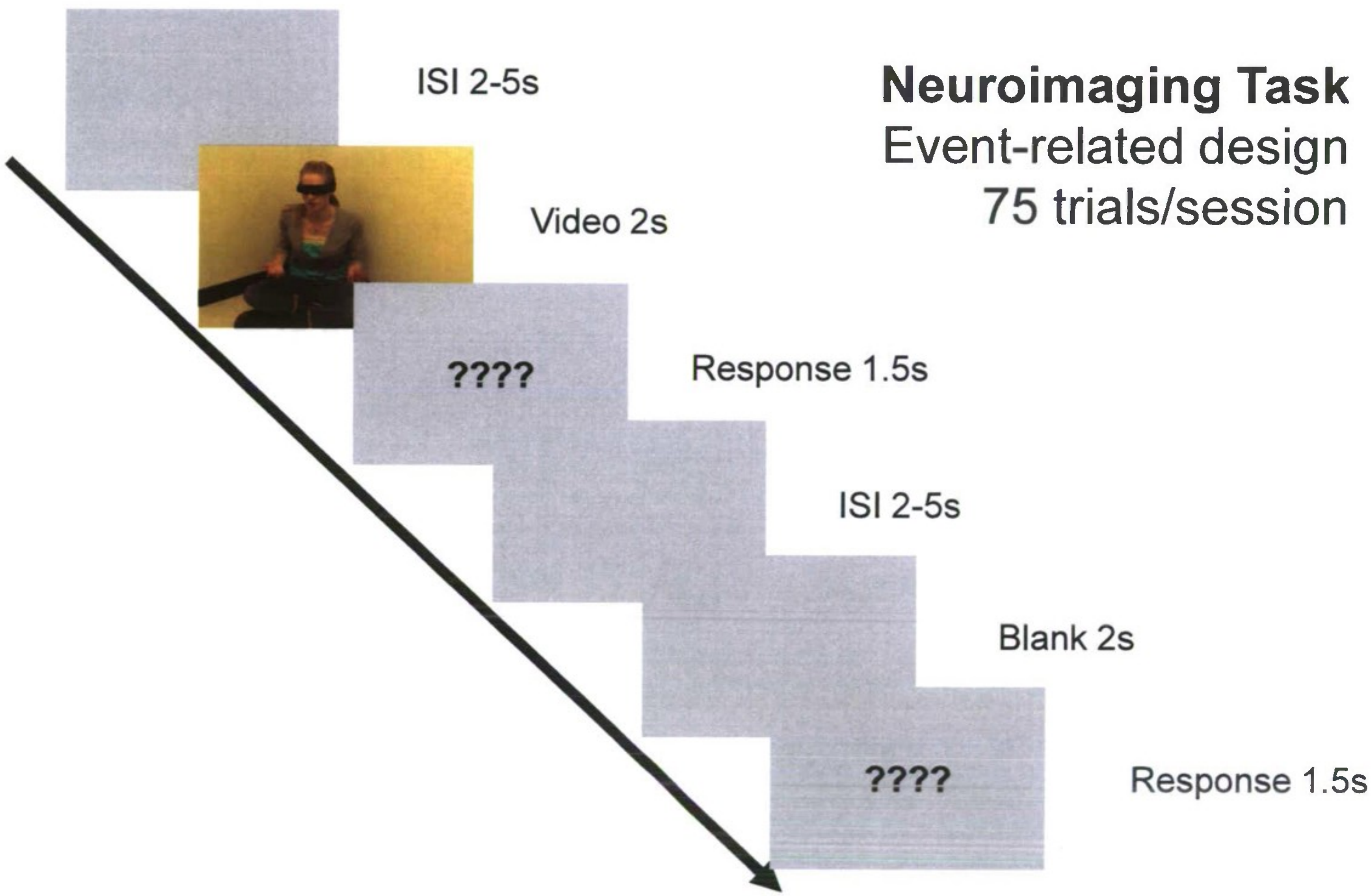
Experimental Overview

- Outcomes: **Mirror Neuron System (MNS)** response measured with **functional magnetic resonance imaging (fMRI)**
  - Does motor or visual training increase the neural response in MNS to viewing actions?
  - Measurement of blood oxygen level-dependent (BOLD) response as participants watch videos of motor task they are being trained on



Experimental Overview

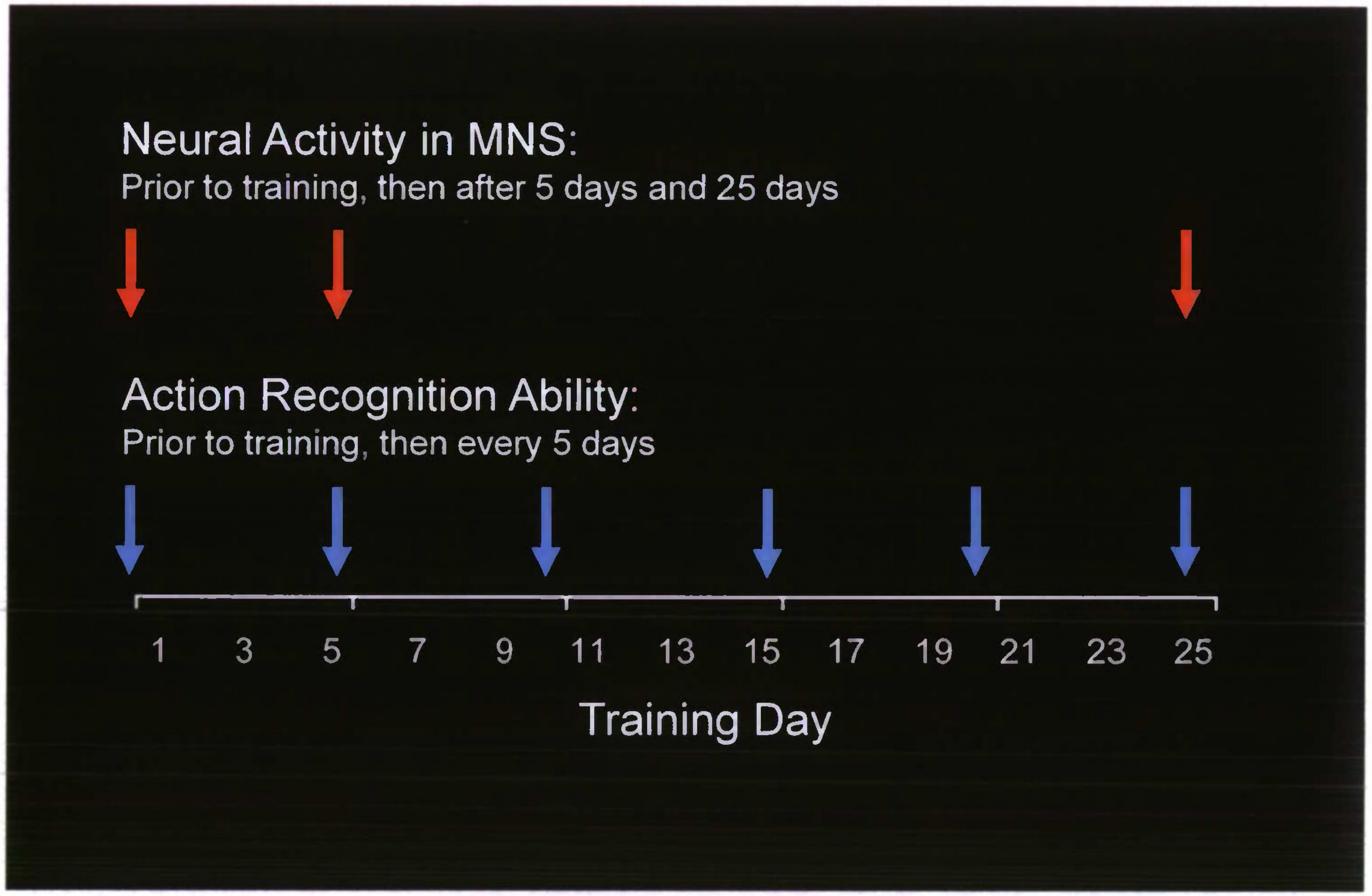
- Outcomes: **fMRI of MNS during of Action Recognition**



Neuroimaging Task
Event-related design
75 trials/session

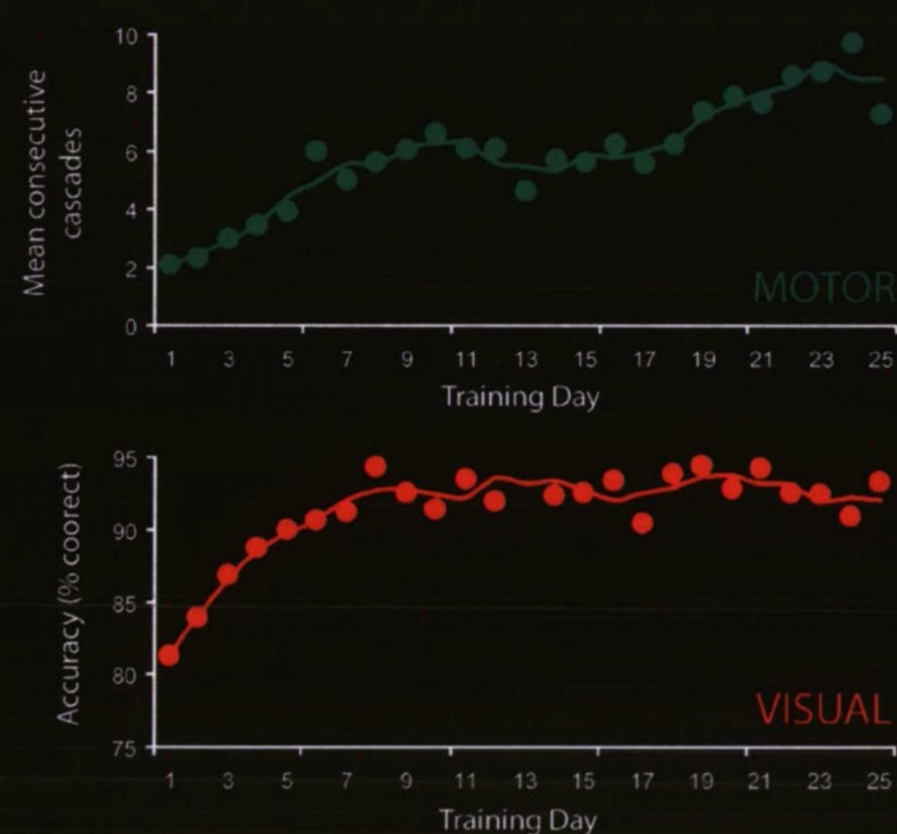
Experimental Overview

- Timeline of Outcome Measurement



RESULTS: TRAINING

- Training improved performance of the **nonvisual motor** and **visual nonmotor** task



MOTOR

Performance increased with training, $F(2, 20) = 11.87$, $p<0.001$, with improvement from Day 1 to Day 5, $F(1, 10) = 14.95$, $p<0.001$, and from Day 5 to Day 25, $F(1, 10) = 6.4$, $p<0.05$.

VISUAL

Performance increased with training, $F(2, 20) = 14.14$, $p<0.001$, with improvement from Day 1 to Day 5, $F(1, 10) = 24.50$, $p<0.001$, with a trend from Day 5 to Day 25, $F(1, 10) = 4.1$, $p=0.07$.

RESULTS GOAL 1

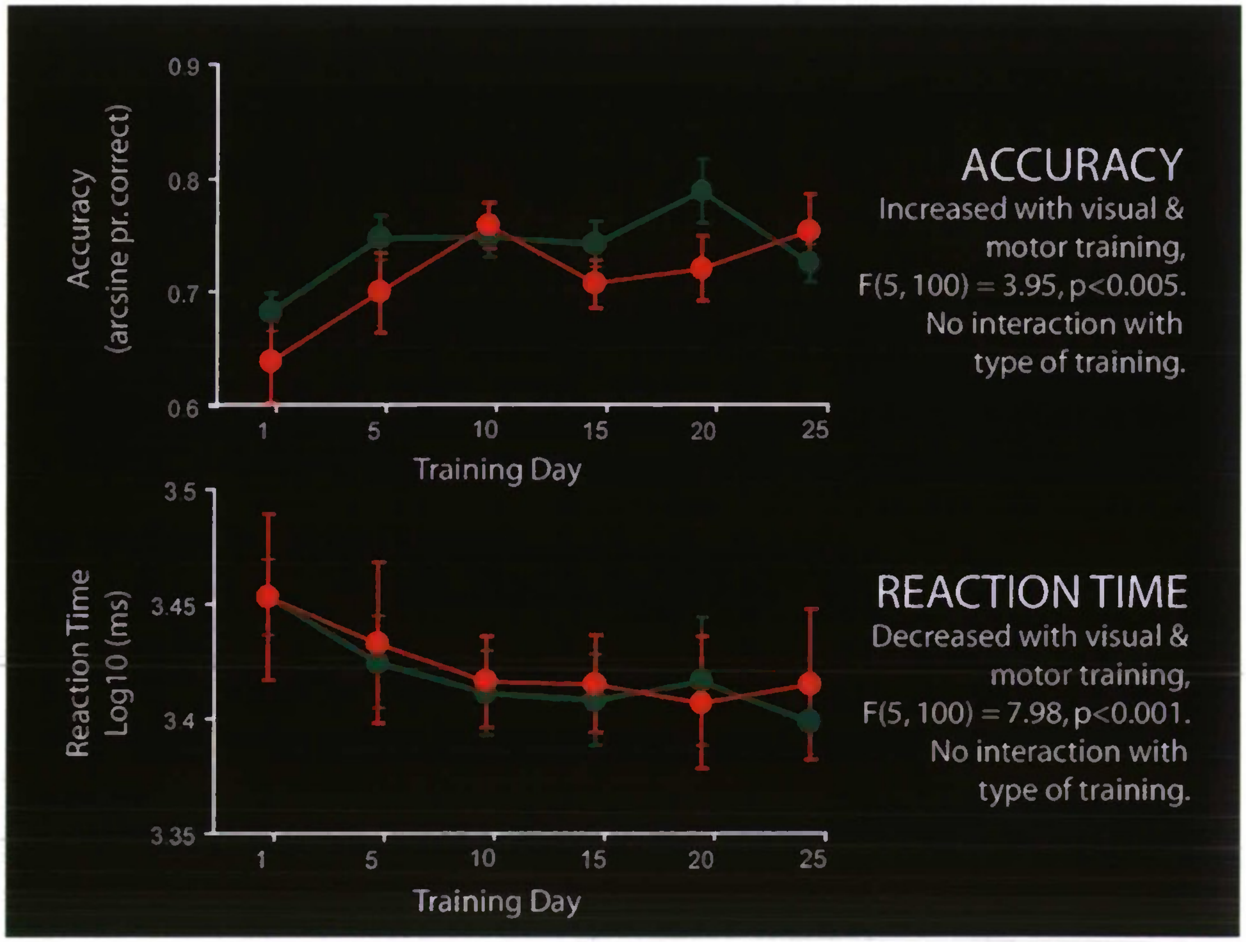
- **Goal 1**: To determine the trajectory from naïve to expert in action recognition
  - **Action Recognition Ability**
    - Psychophysical testing
  - Neural activity in **MNS** during **Action Recognition**
    - Functional Magnetic Resonance Imaging (fMRI)

RESULTS GOAL 1

- **Action Recognition Ability**
  - Both groups showed improvement in ability to predict catches and drops from point-light videos
  - No advantage conferred by motor training
  - Overall accuracy low – task difficulty?

RESULTS GOAL 1

- Similar changes in **Action Recognition Ability** with nonvisual motor and visual nonmotor training

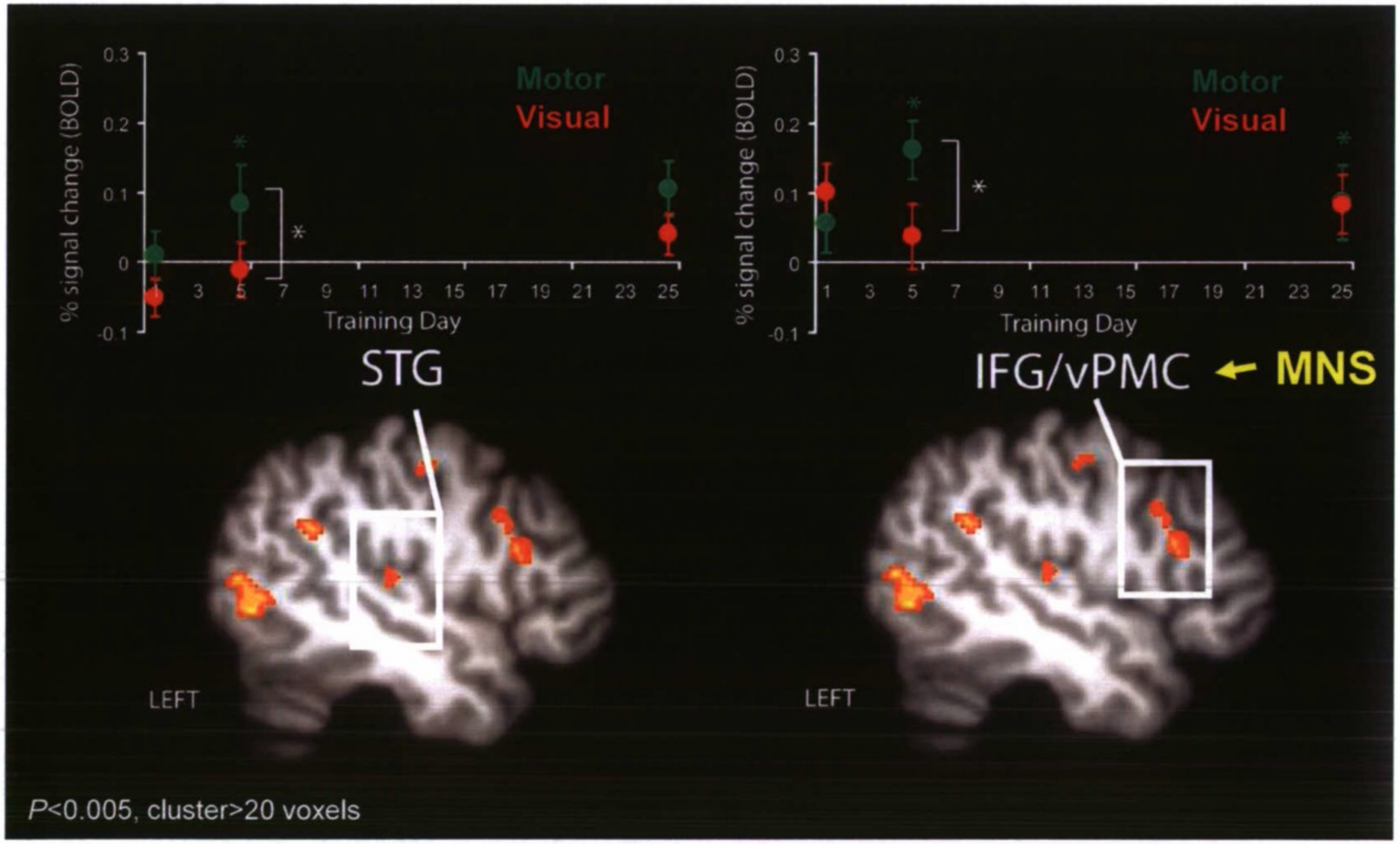


RESULTS GOAL 1

- **Two phases of neural changes as a result of nonvisual motor training**
  - Initial increase from Day 1 to Day 5:
    - Supplementary Motor Area (SMA)
    - **Left Inferior Frontal/Ventral Premotor (IFG/vPMC) - MNS**
    - Left Primary Motor (M1)
    - Right & Left Parietal Operculum (PO/IPL)
    - Right Medial Intraparietal Sulcus (mIPS)
    - Right & Left Superior Temporal Gyrus (STG)
  - Later increases from Day 1 to Day 25
    - **Right Dorsal and Ventral Premotor (dPMC & vPMC) - MNS**
    - **Left Inferior Parietal Lobule (IPL) - MNS**
  - Decrease from Day 5 to Day 25
    - Right and Left Inferior Occipital Sulcus (MT+)

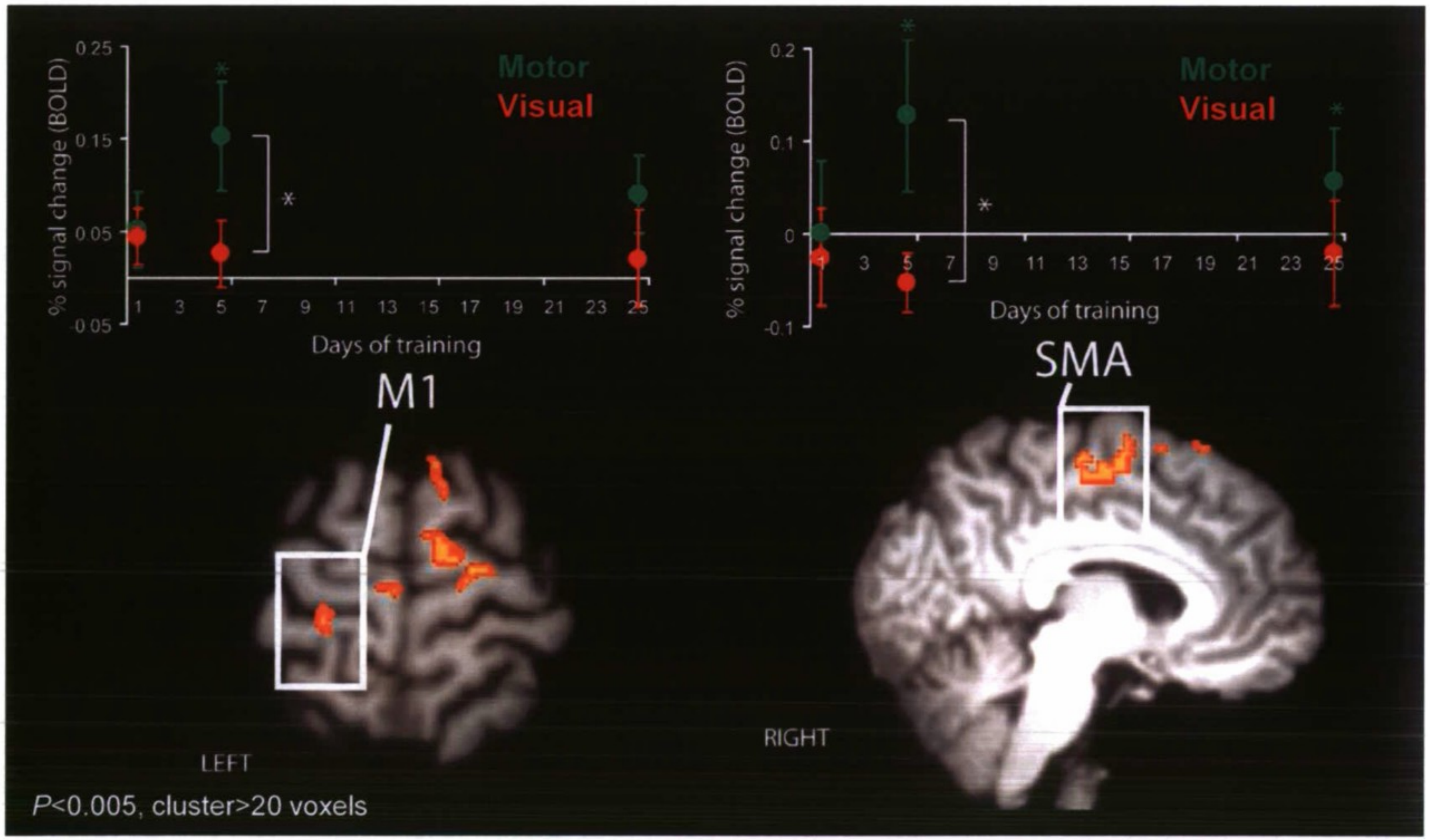
RESULTS GOAL 1

- Initial greater fMRI increases during action recognition in **nonvisual motor** than **visual nonmotor** Day 1 to Day 5



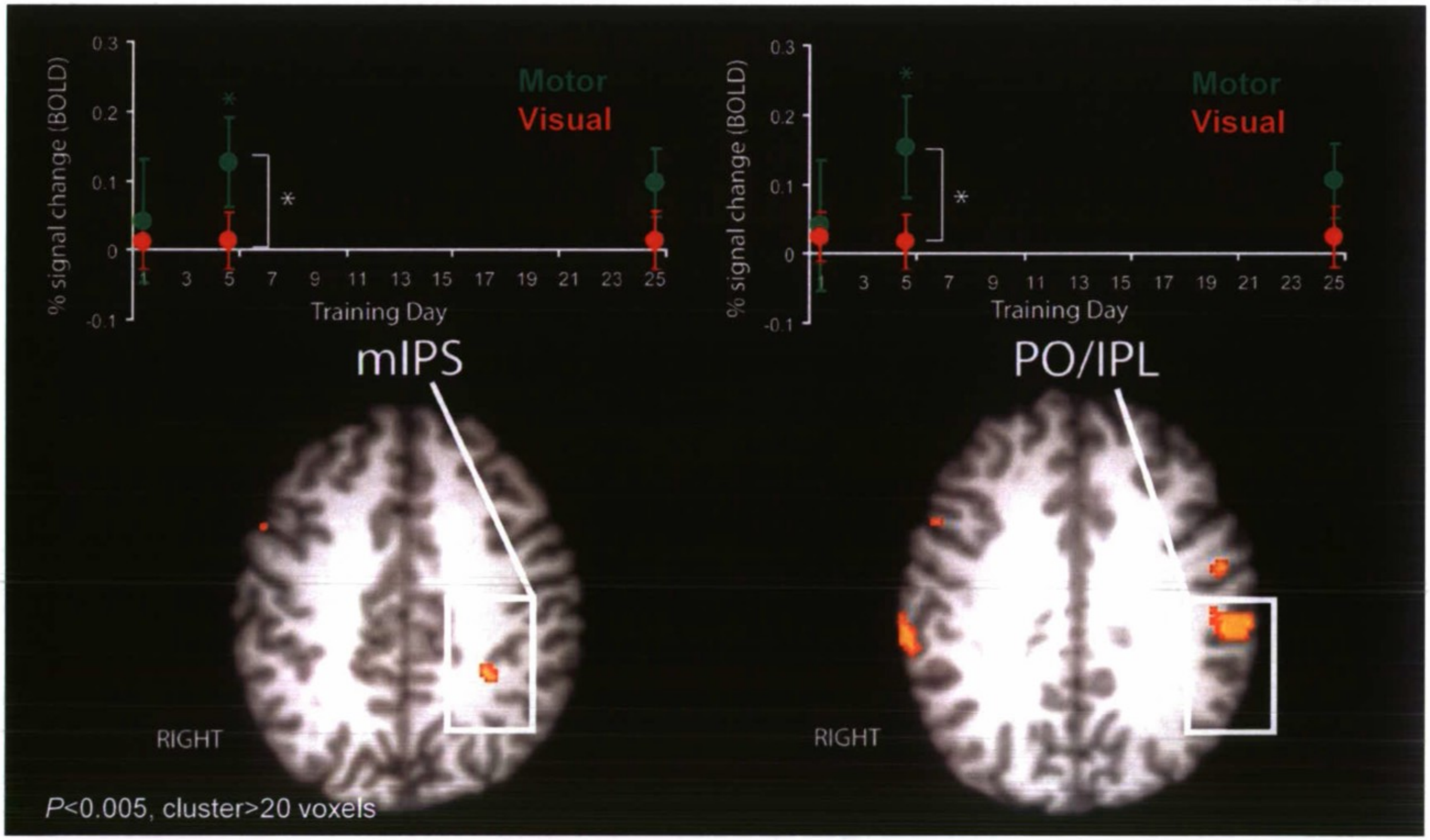
RESULTS GOAL 1

- Initial greater fMRI increases during action recognition in **nonvisual motor** than **visual nonmotor** Day 1 to Day 5



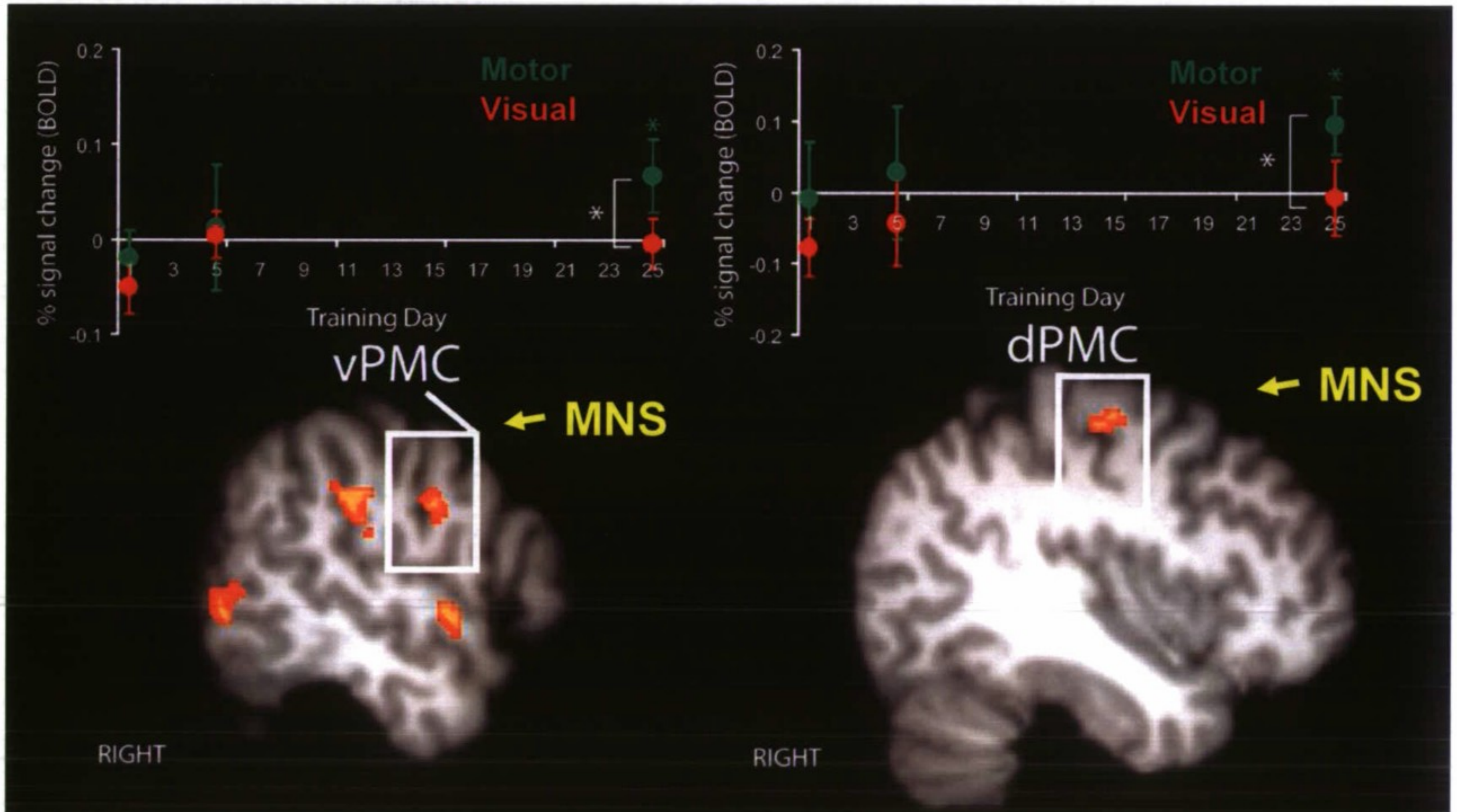
RESULTS GOAL 1

- Initial greater fMRI increases during action recognition in **nonvisual motor** than **visual nonmotor** Day 1 to Day 5



RESULTS GOAL 1

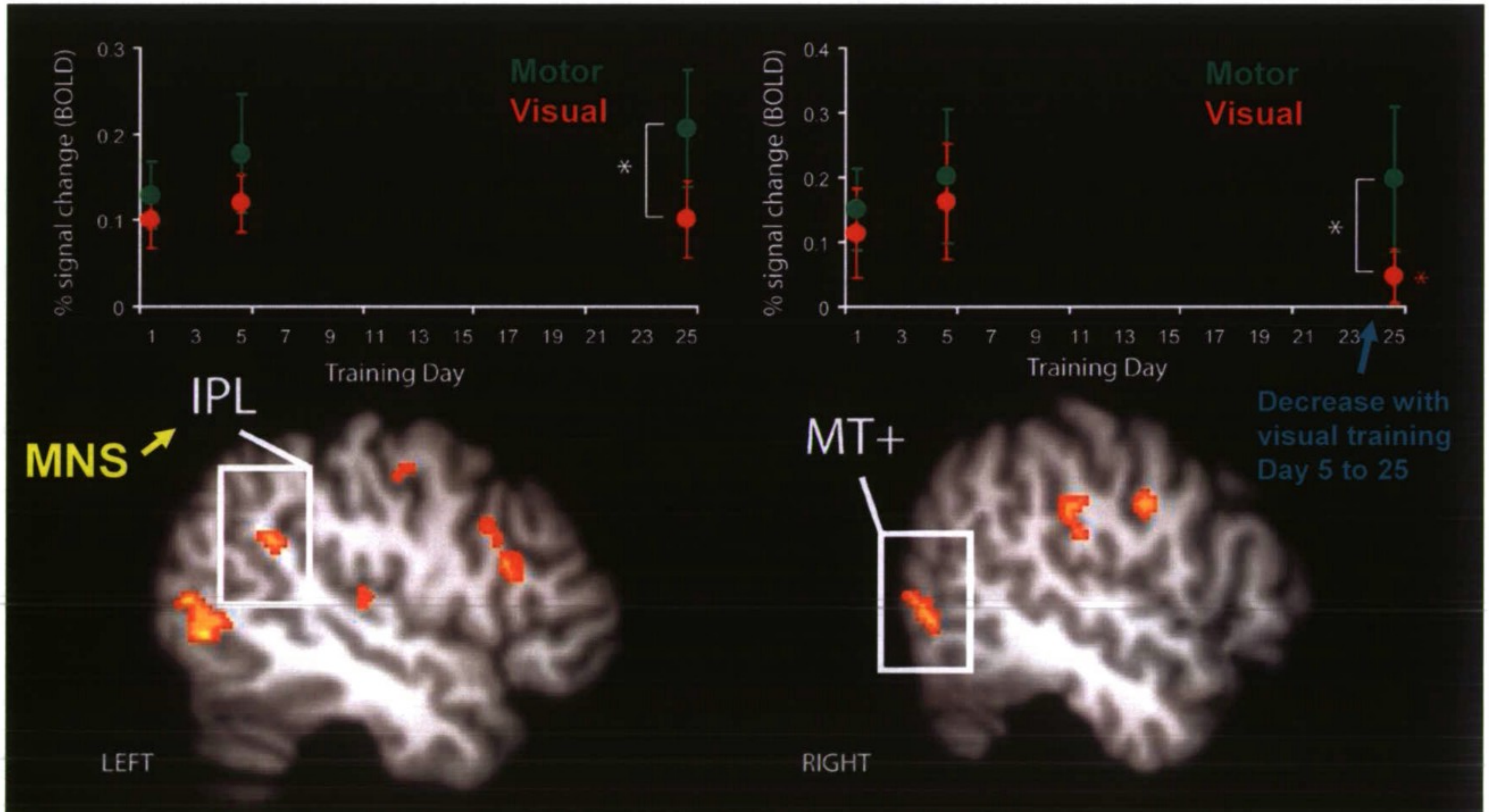
- Later fMRI increases during action recognition in **nonvisual motor** than **visual nonmotor** Day 1 to Day 25



P<0.005, cluster>20 voxels

RESULTS GOAL 1

- Later fMRI increases during action recognition in **nonvisual motor** than **visual nonmotor** Day 1 to Day 25



P<0.005, cluster>20 voxels

RESULTS GOAL 1

- fMRI Responses in **MNS** during **Action Recognition**
  - Neural responses in **MNS** showed greater increases with **nonvisual motor** training relative to **visual nonmotor** training
  - Broader network of visuomotor regions showed greater increases with **nonvisual motor** training relative to **visual nonmotor** training
  - Decreases in visual motion processing regions with **visual nonmotor** training

RESULTS GOAL 1 SUMMARY

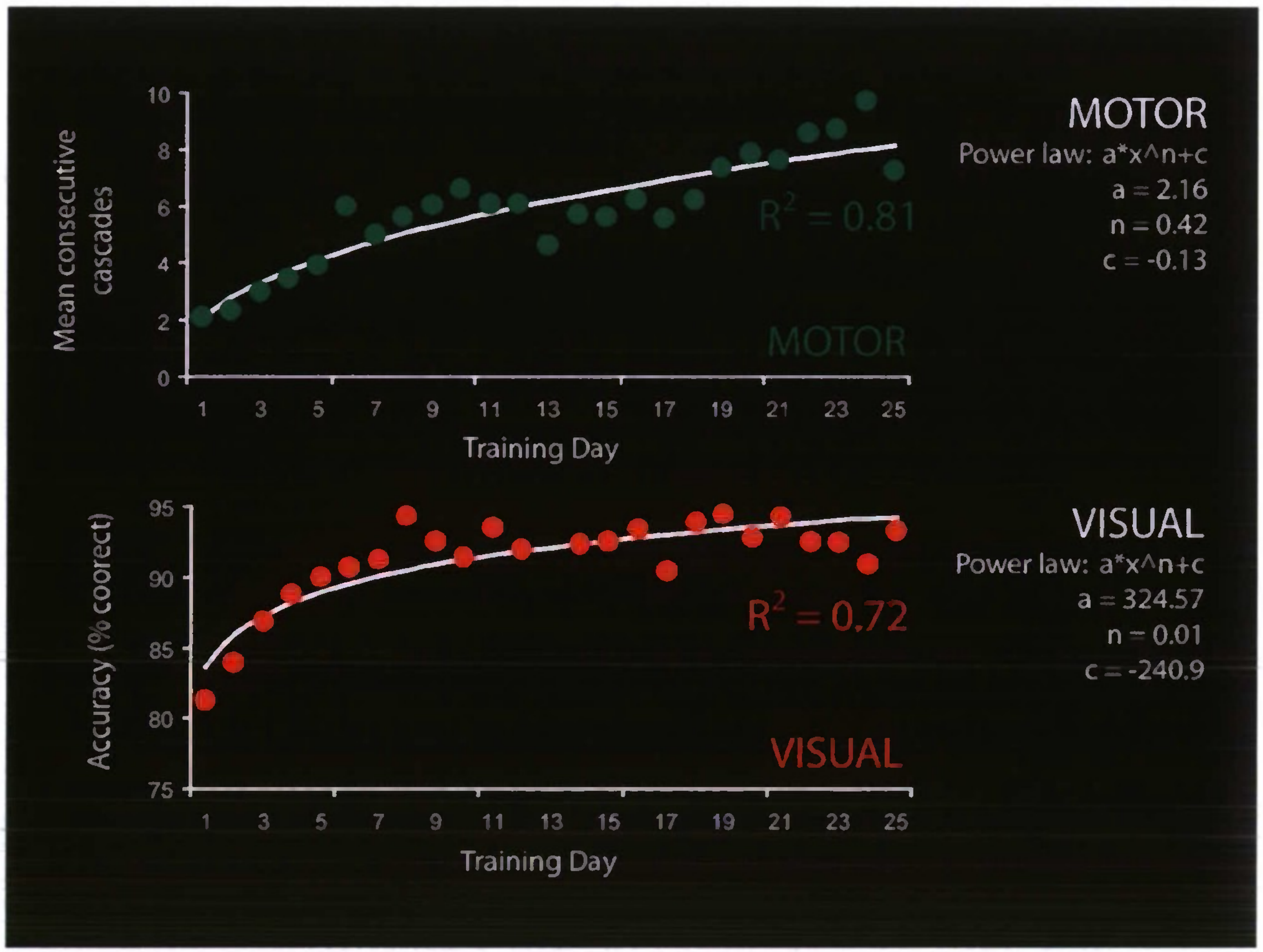
- **Goal 1:** To determine the trajectory from naïve to expert in action recognition
  - Similar improvements in action recognition ability with **nonvisual motor** and **visual nonmotor training**
  - **Nonvisual motor training** leads to an increase in MNS activity (and broader network of visuomotor regions) during action recognition, relative to **visual nonmotor training**
  - **Direct evidence of an increase in the use of *motor representations* during action recognition as a result of motor training**

RESULTS GOAL 2

- **Goal 2:** Establish a quantitative link between a) action performance ability and b) action recognition ability & neural activity in MNS
  - Examine the extent to which increases in action performance predict changes in action recognition
    - Does learning curve from nonvisual motor and visual nonmotor training predict action recognition ability and fMRI response?

RESULTS GOAL 2

- Moderate fit of power law function to learning in **nonvisual motor** and **visual nonmotor** conditions



RESULTS GOAL 2

- Power law function only moderate predictor of **Action Recognition Ability**
  - Nonvisual Motor: Accuracy average $R^2 = 0.16$
    RT average $R^2 = 0.63$
  - Visual Nonmotor: Accuracy average $R^2 = 0.30$
    RT average $R^2 = 0.45$

RESULTS GOAL 2

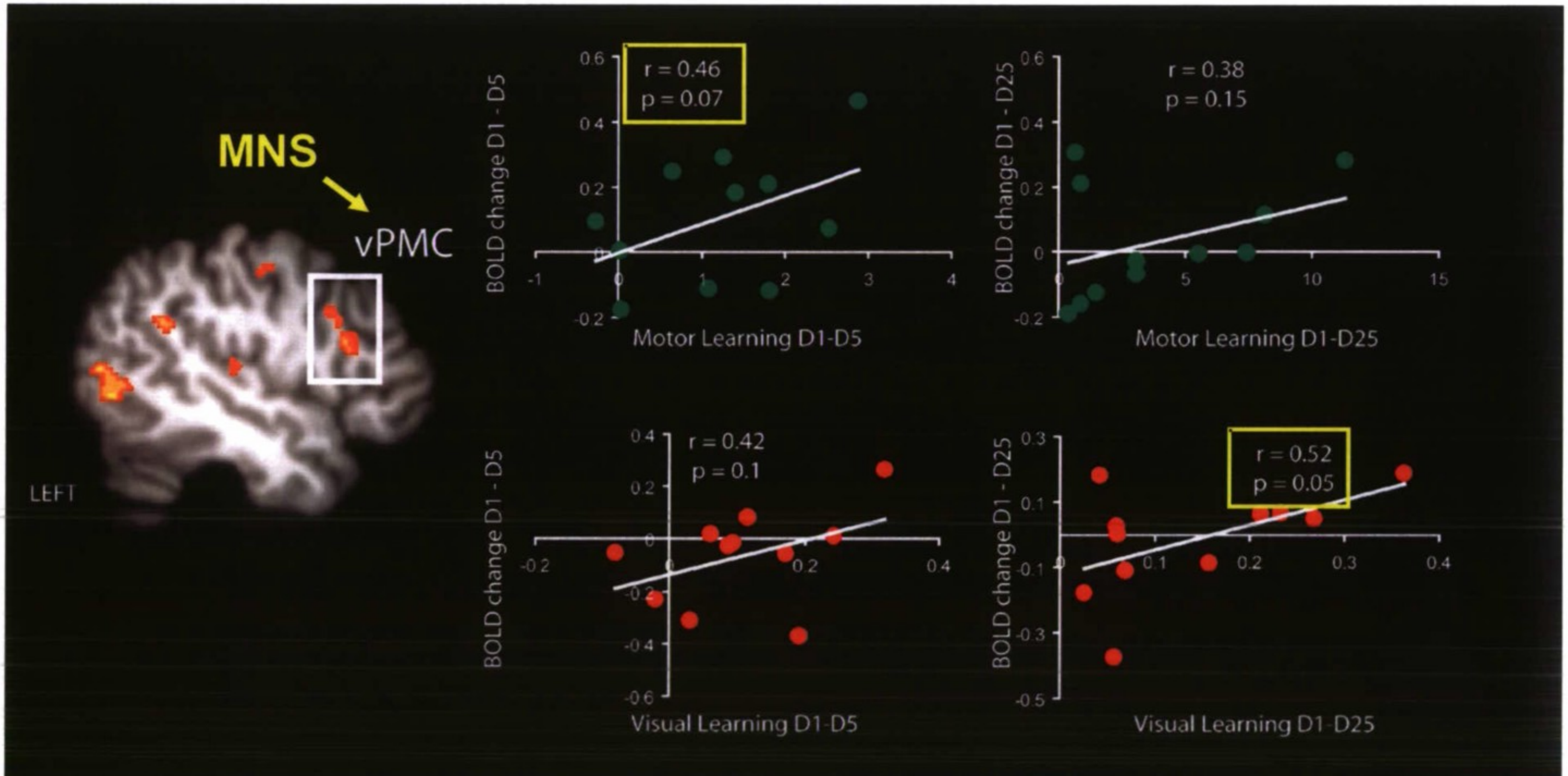
- Power law function did not predict amount of fMRI activity change from Days 1 to 5 or Day 1 to 25
  - Low (<0.2) or negative correlations between predicted BOLD signal change from Day 1 to 5 (and Day 1 to 25) and observed signal change in both training conditions
- Two phases of changes to neural activity
  - Power law assumes a single process

RESULTS GOAL 2

- Examined correlation between raw performance changes and BOLD signal changes
  - Day 1 to 5
  - Day 1 to 25
  - Day 5 to 25

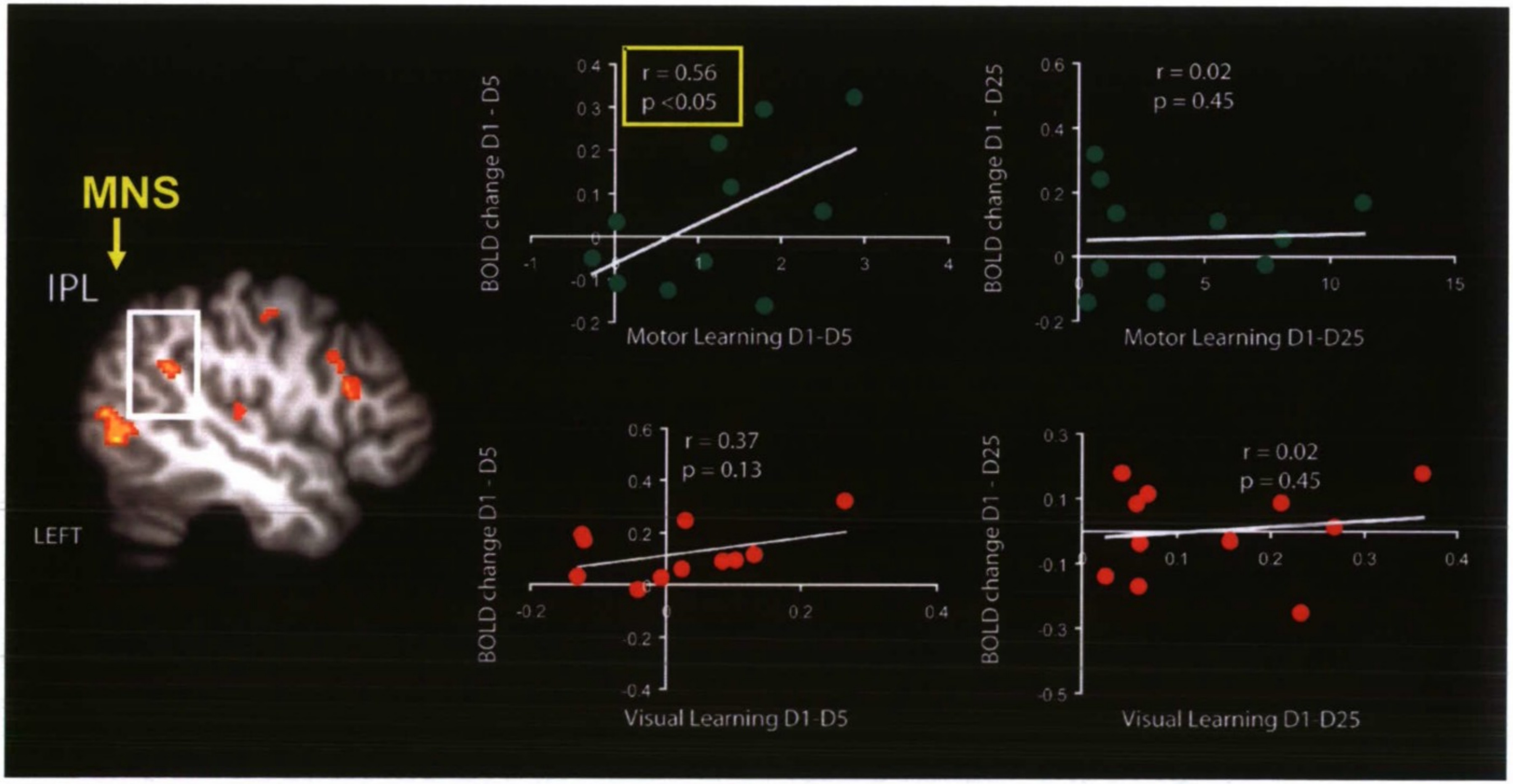
RESULTS GOAL 2

- Correlation between **nonvisual motor** learning and left **vPMC** increase from Day 1 to 5, and **visual nonmotor** learning and left **vPMC** increase from Day 1 to 25



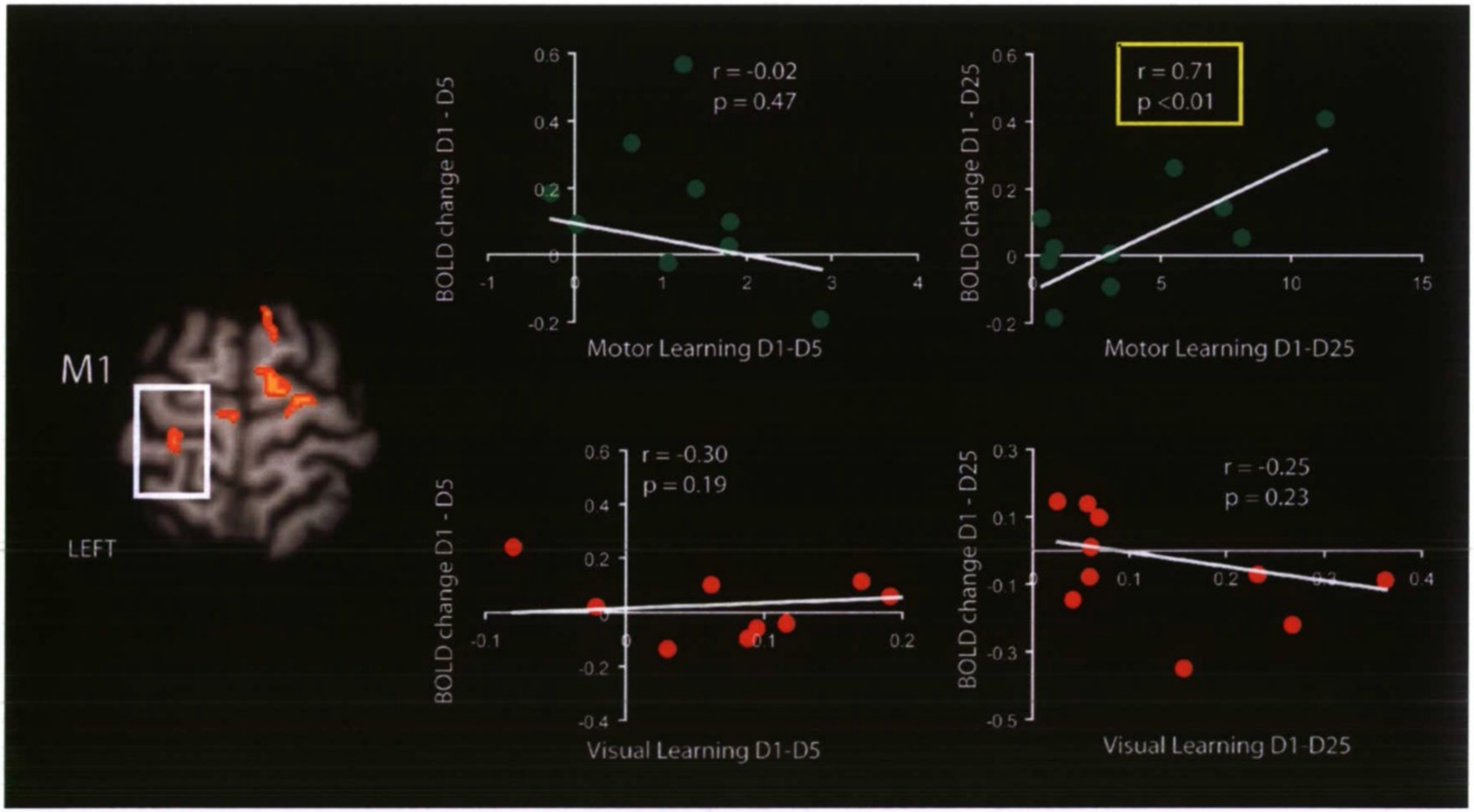
RESULTS GOAL 2

- Correlation between **nonvisual motor** learning and left **IPL** increase from Day 1 to 5



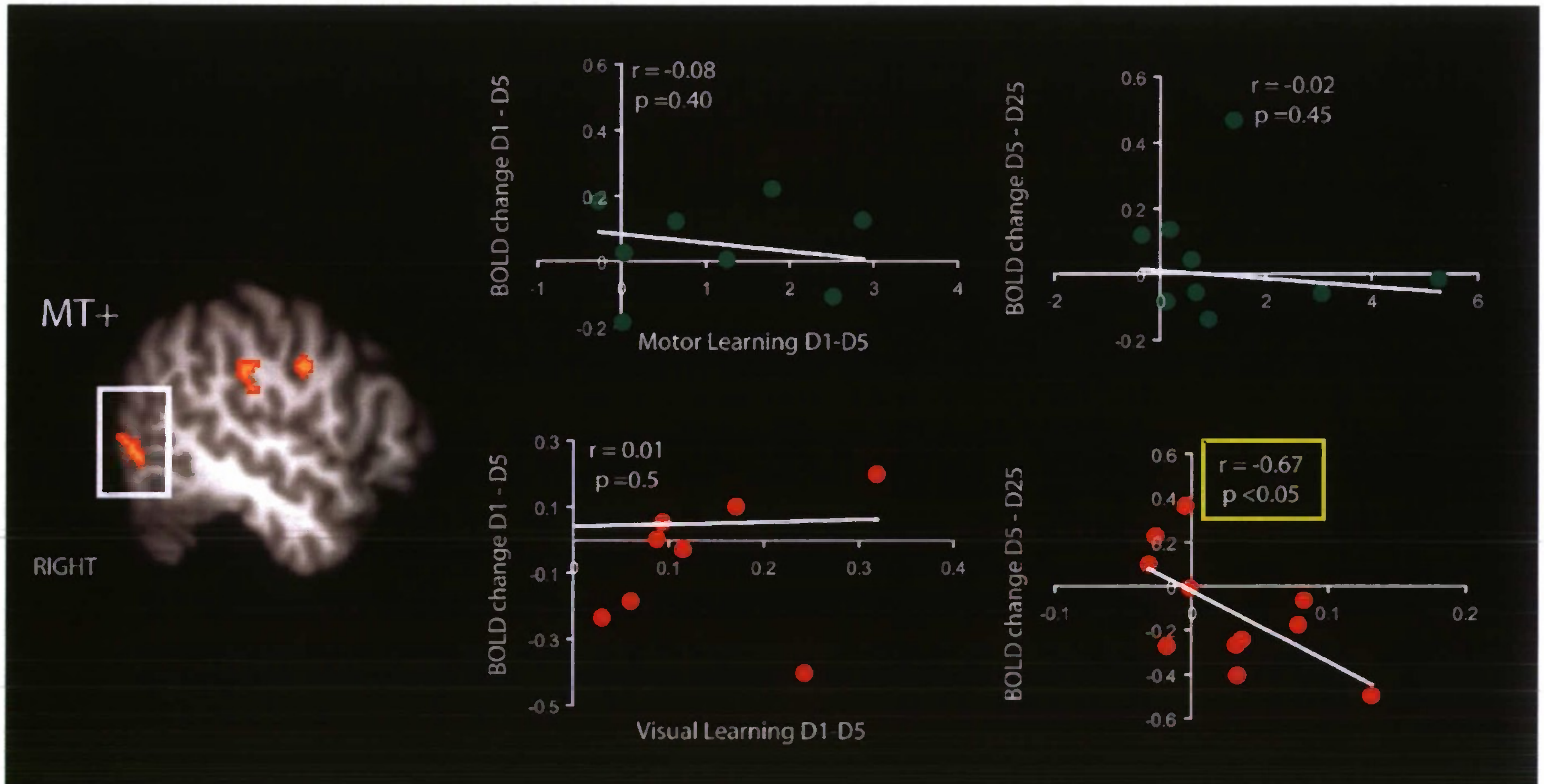
RESULTS GOAL 2

- Correlation between **nonvisual motor** learning and left **M1** increase from Day 1 to 25



RESULTS GOAL 2

- Correlation between **visual nonmotor** learning and right **MT+** decrease from Day 5 to 25



RESULTS GOAL 2 SUMMARY

- **Goal 2:** Establish a quantitative link between a) action performance ability and b) action recognition ability & neural activity in MNS
  - Power law learning curve of action performance moderate predictor of action recognition ability – did not predict neural activity
  - Raw performance changes in **nonvisual motor** condition significantly correlated with changes in neural activity in **vPMC** and **IPL** (both part of human MNS) and primary motor cortex
  - Performance changes in **visual nonmotor** condition significantly correlated with increase in **vPMC**, and decrease in **MT+**

CONCLUSIONS

- **Nonvisual motor** learning leads to increased neural activity in **MNS** and broader visuomotor network
  - Rapid initial learning in **vPMC** and broader network
  - Later learning in **dPMC** and **IPL**
- Increase in **MNS** and **primary motor cortex** correlated with **motor** performance improvement
  - Strong evidence for the role of motor representations in action recognition
- **Visual** learning associated with decreased activity in motion processing regions

Next Steps

- **DARPA Hard Problem:** Ability to engage in motor practice can be limited by environment/context
- Focal stimulation of MNS via TMS during **motor learning** could accelerate action recognition abilities
- **Could focal stimulation of MNS via TMS during visual learning "mimic" the effects of motor learning?**

Next Steps

- Focal stimulation of MNS during **motor** learning could potentially accelerate action recognition abilities
  - Transcranial Magnetic Stimulation (TMS)
    - Stimulation of human motor cortex via TMS can enhance formation of motor engram (Butefisch et al., 2004, *J Neurophysiol*)
  - Effects of daily TMS during **motor learning** on action recognition abilities
  - Potential stimulation regions
    - primary motor cortex
    - vPMC (MNS)
    - IPL (MNS)
    - MT+

Next Steps

- Could focal stimulation of MNS via TMS during **visual learning** “mimic” the effects of motor learning?
  - Effects of daily TMS to MNS during **visual practice** on action recognition abilities
  - Combine with complex, dynamic **virtual reality** environment

Future Research Initiative

- Understanding the link between motor and visual representations during action recognition
  - Question 1: How can expertise in action recognition be accelerated?
    - TMS to stimulate MNS regions during **motor** learning
    - TMS to stimulate MNS regions during **visual** learning
- Military applications:
  - *Enhancing* or *mimicking* the effects of motor practice via TMS when such practice is limited or impossible may assist in training for new battlefield scenarios

Future Research Initiative

- Understanding the link between motor and visual representations during action recognition
  - Question 2: Action learning typically involves both visual and motor learning – how do these different cues combine, how do they contribute to action recognition, and what happens when they conflict?
    - Bayesian integration of visual and motor cues?
    - Does the reliance on visual or motor representation depend on cue reliability during a) learning or b) or action recognition?
    - Does the reliance on visual or motor representation depend on the type of response (button press, reach to grasp) or if under stress during action recognition?

Future Research Initiative

- Understanding the link between motor and visual representations during action recognition
  - Question 2: Action learning typically involves both visual and motor learning – how do these different cues combine, how do they contribute to action recognition, and what happens when they conflict?

- Military applications:
  - Effects of conflict between what a soldier has learned via motor practice and what one has learned via observation on action recognition
  - Which does the soldier rely on in the heat of battle?

Future Research Initiative

- Understanding the link between motor and visual representations during action recognition
  - Question 3: How are motor representations used during action recognition organized?
    - Some evidence of somatotopic organization of vPMC – are motor representations in other MNS regions organized according to body part?
    - Are action kinematics and dynamics represented independently, and to what extent do each influence action recognition?
    - How can one minimize the negative influence of observing incompatible actions during motor performance?

Future Research Initiative

- Understanding the link between motor and visual representations during action recognition
  - Question 3: How are motor representations used during action recognition organized?

- Military applications:
  - What strategies can a soldier use when engaged with another individual (enemy or team member) to minimize the influence of incompatible actions?

Future Research Initiative

- Understanding the link between motor and visual representations during action recognition
  - Question 4: What is the basis of individual differences in action recognition abilities and neural activity in MNS?
    - Genetic differences (COMT, DBH, BDNF)
    - Personality differences
    - Motor co-ordination
  - Are any effects on action recognition and MNS mediated by an effect on motor learning?

Future Research Initiative

- Understanding the link between motor and visual representations during action recognition
  - Question 4: What is the basis of individual differences in action recognition abilities and neural activity in MNS?

- Military applications:
  - How can soldiers with high abilities in action recognition be identified, and how can soldiers with low abilities be effectively trained?